

Decoding the Amplitude-Modulated Part the DCF77 Longwave Time Signal by using the Goertzel Algorithm

1st Leander Hackmann

*Master Embedded Systems Engineering
FH Dortmund*

Dortmund, Germany

Mat.-Nr.: 7217912, leander.hackmann001@stud.fh-dortmund.de

Abstract—The DCF77, a long wave time signal transmitter that is located near Frankfurt am Main in Germany, is the primary source of time information for radio-controlled clocks in Europe. Its signal consists of a phase and an amplitude-modulated part, both containing the time information. Devices that use the signal usually consist of an amplitude modulation long wave receiver, often realized by using a dedicated integrated circuit, and an application processor. In this paper, an alternative approach for the demodulation of the amplitude-modulated part of the signal, without the need for specialized analog circuitry and only a minimal amount of simple hardware components, is presented. This is done by utilizing direct-sampling software-defined radio techniques together with leveraging the efficiency of the Goertzel algorithm. As a result, the presented approach removes the need for most of the usually employed analog circuitry, leaving only a front-end amplifier, and therefore effectively proposes a new type of design where the receiver is implemented inside the application processor. The employed lightweight algorithms keep it realizable on a system with limited resources, which is shown in an example implementation on a Arm Cortex-M3 microcontroller.

Index Terms—DCF77, Goertzel, Digital Signal Processing, Time Signal, Software Defined Radio

I. INTRODUCTION

Radio controlled clocks are very popular because they don't require periodical re-adjustment in comparison to common mechanical or quartz-powered clocks. Instead, the information about the current time is obtained from a RF-signal that is transmitted by an official authority that ensures its availability and correctness. The probably most important time signal in Europe is transmitted by the station DCF77 from Mainflingen, a city in Germany that is close to Frankfurt am Main. The station is operated by a private company that is commissioned by the Physikalisch-Technische Bundesanstalt (PTB) which also supplies the current time information, generated by two caesium clocks and two caesium fountains. Its operating frequency lies in the long wave area at 77.5 kHz and the time signal uses simple modulation techniques (amplitude and phase-modulation) and transmits with 100 kW Effective Isotropic Radiated Power (EIRP) to enable the reception of the signal in relatively close distances (up to 2000 km) with simple technical equipment [2].

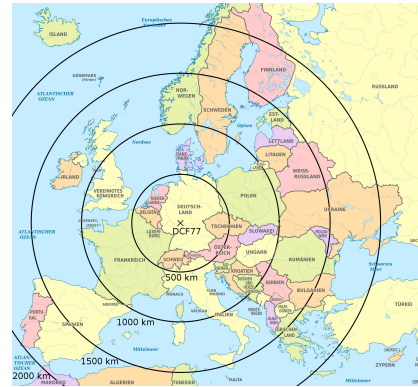


Fig. 1. Coverage of the DCF77 signal. Adapted from [1]

End-user devices usually make use of the amplitude-modulated part of the signal by using an amplitude modulation receiver, often a by employing specialized integrated circuit, together with a rather big ferrite-rod antenna to obtain the time signal. This time signal then needs further hardware, often in form of a microcontroller used as the application processor, to decode and retrieve the actual time information. With the increasing availability of computation power and Digital Signal Processing (DSP) capabilities inside cheap mixed-signal microcontrollers, which are already used to process the time information, the idea to replace the analog receiver portion with a Software Defined Radio (SDR) is more or less obvious. Moving the receiver into the application processor would allow for a simpler hardware design by shrinking down the complexity and the parts count of the external analog circuitry. In fact, only a tuned antenna with a basic pre-amplifier is needed.

In this paper, a straightforward principle for designing a lightweight receiver for the DCF77, based on SDR-techniques, is presented. After taking a look at the structure of the DCF77 signal, the theoretical operation principle of the receiver is explained and shown in a MATLAB simulation. To further underline the simplicity and the possibility to implement the principle on a system with limited resources, a demonstration

on a Arm Cortex-M3 microcontroller is shown.

II. THE DCF77 SIGNAL

The DCF77 station operates in the long wave area at a frequency of 77.5 kHz. Its operation started with transmitting a frequency standard in 1959. In 1973, the transmission of the current time information was added to the signal by using amplitude modulation. To allow a reception under more challenging conditions and with a higher resolution and accuracy, the same time information is also added to the signal since 1983 by using phase-modulation [3]. The two different parts of the signal that result out of the parallel amplitude and the phase-modulation can be used for different use-cases that are separated by the requirements regarding the resolution, accuracy, and the reliability of the obtained time information. Whereas the amplitude-modulated part is mainly used for general-purpose time application with low resolution requirements, the phase-modulated part is usually used for specialized applications that require a higher resolution, accuracy, and reliability. Although being considered as low in comparison to what is achievable by analyzing the phase-modulated part, the usually observed accuracy uncertainty when using the amplitude-modulated part it is still well below 1 s, being 100 ms [2]. When using the phase-modulated part, a standard deviation of $\pm 2 \mu\text{s}$ to $\pm 22 \mu\text{s}$ from the atomic clock to the receiving device can be observed [4].

As the amplitude-modulated part allows simplistic receiver designs through its straightforward modulation scheme, it is used in the principle presented in this paper and therefore a focus is put on explaining this part of the DCF77 signal. The time information, represented as a series of binary symbols, is modulated onto the carrier with a frequency of 77.5 kHz by using Amplitude-Shift Keying (ASK). Every symbol has the duration of exactly 1 s, with a part that is either 100 ms or 200 ms long where it has a value to zero. This the duration of this "gap" is used to encode respectively a 0 or a 1 and effectively switches the strength of the carrier between 15% and 100% [5].

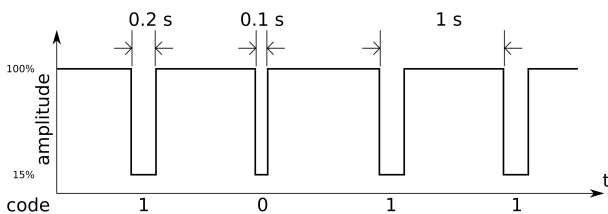


Fig. 2. Symbol encoding of the DCF77 signal. From [1]

To allow the detection of a new minute, the gap is left out between the last (59) second of the ongoing and the first (0) second of the next minute. By using this scheme, a dataframe consisting out 59 Bit, starting at second one, can be transmitted every minute. Bit 0 to 19 are used to send encrypted weather data, to notify the PTB in case of errors in the transmitter, to announce an upcoming switch to or from Daylight Saving Time (DST), to show if DST is currently

enabled or not, and to announce an upcoming leap second [5]. As the decryption of the weather date requires a specialized third-party integrated circuit and the notification bit is only important for the PTB, these parts of the frame are discarded by most applications. The leftover Bits 20 to 58 are used to represent the current time and date in Binary Coded Decimal (BCD) format, including parity bits for recognizing errors.

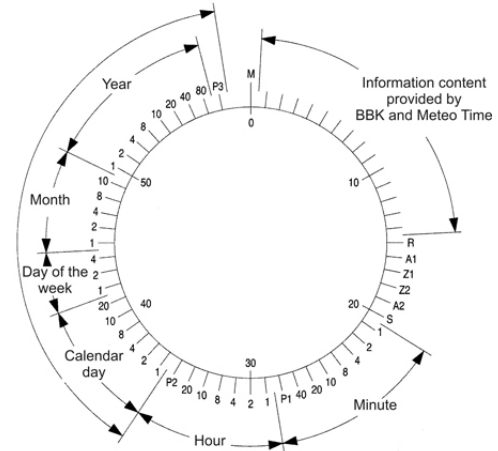


Fig. 3. Data frame encoding of the DCF77 signal. From [5]

This means that a receiver needs to run at least for 39 s after powerup to receive one whole block containing the current time information. In reality, this period is usually longer because the receiver needs to adapt to the current receiving conditions. These conditions underly a lot of influences, including temporary fading, electromagnetic noise from the close environment or varying signal strengths during different times of the day.

III. PRINCIPLE OF A DCF77 RECEIVER

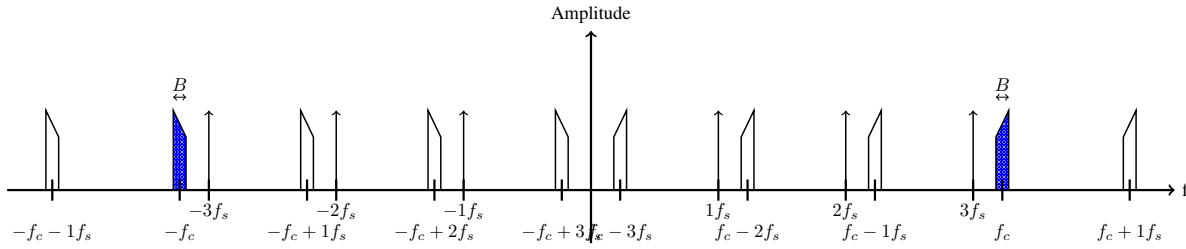
A. Maintaining the Integrity of the Specifications

The IEEEtran class file is used to format your paper and style the text. All margins, column widths, line spaces, and text fonts are prescribed; please do not alter them. You may note peculiarities. For example, the head margin measures proportionately more than is customary. This measurement and others are deliberate, using specifications that anticipate your paper as one part of the entire proceedings, and not as an independent document. Please do not revise any of the current designations.

IV. PREPARE YOUR PAPER BEFORE STYLING

Before you begin to format your paper, first write and save the content as a separate text file. Complete all content and organizational editing before formatting. Please note sections IV-A to IV-H below for more information on proofreading, spelling and grammar.

Keep your text and graphic files separate until after the text has been formatted and styled. Do not number text heads— \LaTeX will do that for you.



A. Abbreviations and Acronyms

Define abbreviations and acronyms the first time they are used in the text, even after they have been defined in the abstract. Abbreviations such as IEEE, SI, MKS, CGS, ac, dc, and rms do not have to be defined. Do not use abbreviations in the title or heads unless they are unavoidable.

B. Units

- Use either SI (MKS) or CGS as primary units. (SI units are encouraged.) English units may be used as secondary units (in parentheses). An exception would be the use of English units as identifiers in trade, such as “3.5-inch disk drive”.
- Avoid combining SI and CGS units, such as current in amperes and magnetic field in oersteds. This often leads to confusion because equations do not balance dimensionally. If you must use mixed units, clearly state the units for each quantity that you use in an equation.
- Do not mix complete spellings and abbreviations of units: “Wb/m²” or “webers per square meter”, not “webers/m²”. Spell out units when they appear in text: “. . . a few henries”, not “. . . a few H”.
- Use a zero before decimal points: “0.25”, not “.25”. Use “cm³”, not “cc”).

C. Equations

Number equations consecutively. To make your equations more compact, you may use the solidus (/), the exp function, or appropriate exponents. Italicize Roman symbols for quantities and variables, but not Greek symbols. Use a long dash rather than a hyphen for a minus sign. Punctuate equations with commas or periods when they are part of a sentence, as in:

$$a + b = \gamma \quad (1)$$

Be sure that the symbols in your equation have been defined before or immediately following the equation. Use “(1)”, not “Eq. (1)” or “equation (1)”, except at the beginning of a sentence: “Equation (1) is . . .”

D. \LaTeX -Specific Advice

Please use “soft” (e.g., `\eqref{Eq}`) cross references instead of “hard” references (e.g., (1)). That will make it possible to combine sections, add equations, or change the order of figures or citations without having to go through the file line by line.

Please don’t use the `{eqnarray}` equation environment. Use `{align}` or `{IEEEeqnarray}` instead. The `{eqnarray}` environment leaves unsightly spaces around relation symbols.

Please note that the `{subequations}` environment in \LaTeX will increment the main equation counter even when there are no equation numbers displayed. If you forget that, you might write an article in which the equation numbers skip from (17) to (20), causing the copy editors to wonder if you’ve discovered a new method of counting.

\BibTeX does not work by magic. It doesn’t get the bibliographic data from thin air but from .bib files. If you use \BibTeX to produce a bibliography you must send the .bib files.

\LaTeX can’t read your mind. If you assign the same label to a subsection and a table, you might find that Table I has been cross referenced as Table IV-B3.

\LaTeX does not have precognitive abilities. If you put a `\label` command before the command that updates the counter it’s supposed to be using, the label will pick up the last counter to be cross referenced instead. In particular, a `\label` command should not go before the caption of a figure or a table.

Do not use `\nonumber` inside the `{array}` environment. It will not stop equation numbers inside `{array}` (there won’t be any anyway) and it might stop a wanted equation number in the surrounding equation.

E. Some Common Mistakes

- The word “data” is plural, not singular.
- The subscript for the permeability of vacuum μ_0 , and other common scientific constants, is zero with subscript formatting, not a lowercase letter “o”.
- In American English, commas, semicolons, periods, question and exclamation marks are located within quotation marks only when a complete thought or name is cited, such as a title or full quotation. When quotation marks are used, instead of a bold or italic typeface, to highlight a word or phrase, punctuation should appear outside of the quotation marks. A parenthetical phrase or statement at the end of a sentence is punctuated outside of the closing parenthesis (like this). (A parenthetical sentence is punctuated within the parentheses.)
- A graph within a graph is an “inset”, not an “insert”. The word alternatively is preferred to the word “alternately” (unless you really mean something that alternates).

- Do not use the word “essentially” to mean “approximately” or “effectively”.
- In your paper title, if the words “that uses” can accurately replace the word “using”, capitalize the “u”; if not, keep using lower-cased.
- Be aware of the different meanings of the homophones “affect” and “effect”, “complement” and “compliment”, “discreet” and “discrete”, “principal” and “principle”.
- Do not confuse “imply” and “infer”.
- The prefix “non” is not a word; it should be joined to the word it modifies, usually without a hyphen.
- There is no period after the “et” in the Latin abbreviation “et al.”.
- The abbreviation “i.e.” means “that is”, and the abbreviation “e.g.” means “for example”.

An excellent style manual for science writers is [?].

F. Authors and Affiliations

The class file is designed for, but not limited to, six authors. A minimum of one author is required for all conference articles. Author names should be listed starting from left to right and then moving down to the next line. This is the author sequence that will be used in future citations and by indexing services. Names should not be listed in columns nor group by affiliation. Please keep your affiliations as succinct as possible (for example, do not differentiate among departments of the same organization).

G. Identify the Headings

Headings, or heads, are organizational devices that guide the reader through your paper. There are two types: component heads and text heads.

Component heads identify the different components of your paper and are not topically subordinate to each other. Examples include Acknowledgments and References and, for these, the correct style to use is “Heading 5”. Use “figure caption” for your Figure captions, and “table head” for your table title. Run-in heads, such as “Abstract”, will require you to apply a style (in this case, italic) in addition to the style provided by the drop down menu to differentiate the head from the text.

Text heads organize the topics on a relational, hierarchical basis. For example, the paper title is the primary text head because all subsequent material relates and elaborates on this one topic. If there are two or more sub-topics, the next level head (uppercase Roman numerals) should be used and, conversely, if there are not at least two sub-topics, then no subheads should be introduced.

H. Figures and Tables

a) *Positioning Figures and Tables:* Place figures and tables at the top and bottom of columns. Avoid placing them in the middle of columns. Large figures and tables may span across both columns. Figure captions should be below the figures; table heads should appear above the tables. Insert

TABLE I
TABLE TYPE STYLES

Table Head	Table Column Head		
	Table column subhead	Subhead	Subhead
copy	More table copy ^a		

^aSample of a Table footnote.

figures and tables after they are cited in the text. Use the abbreviation “Fig. ??”, even at the beginning of a sentence.

Figure Labels: Use 8 point Times New Roman for Figure labels. Use words rather than symbols or abbreviations when writing Figure axis labels to avoid confusing the reader. As an example, write the quantity “Magnetization”, or “Magnetization, M”, not just “M”. If including units in the label, present them within parentheses. Do not label axes only with units. In the example, write “Magnetization (A/m)” or “Magnetization {A[m(1)]}”, not just “A/m”. Do not label axes with a ratio of quantities and units. For example, write “Temperature (K)”, not “Temperature/K”.

ACKNOWLEDGMENT

The preferred spelling of the word “acknowledgment” in America is without an “e” after the “g”. Avoid the stilted expression “one of us (R. B. G.) thanks ...”. Instead, try “R. B. G. thanks...”. Put sponsor acknowledgments in the unnumbered footnote on the first page.

REFERENCES

Please number citations consecutively within brackets [1]. The sentence punctuation follows the bracket [2]. Refer simply to the reference number, as in [3]—do not use “Ref. [3]” or “reference [3]” except at the beginning of a sentence: “Reference [3] was the first ...”

Number footnotes separately in superscripts. Place the actual footnote at the bottom of the column in which it was cited. Do not put footnotes in the abstract or reference list. Use letters for table footnotes.

Unless there are six authors or more give all authors’ names; do not use “et al.”. Papers that have not been published, even if they have been submitted for publication, should be cited as “unpublished” [4]. Papers that have been accepted for publication should be cited as “in press” [5]. Capitalize only the first word in a paper title, except for proper nouns and element symbols.

For papers published in translation journals, please give the English citation first, followed by the original foreign-language citation [?].

REFERENCES

- [1] -, “DCF77,” 2024, Wikipedia entry. [Online]. Available: <https://de.wikipedia.org/wiki/DCF77>
- [2] D. Priester and P. Hetzel and A. Bauch, “Zeit- und Normalfrequenzverbreitung mit DCF77,” PTB Mitteilungen, 2004, [Online]. Available: https://www.ptb.de/cms/fileadmin/internet/fachabteilungen/abteilung_4/4.4_zeit_und_frequenzverbreitung_mit_dcf77.pdf
- [3] D. Priester and P. Hetzel and A. Bauch, “Zeit- und Normalfrequenzverbreitung mit DCF77: 1959-2009 und darüber hinaus,” PTB Mitteilungen, 2009, [Online]. Available: https://www.ptb.de/cms/fileadmin/internet/fachabteilungen/abteilung_4/4.4_zeit_und_frequenzverbreitung_mit_dcf77.pdf

- [4] P. Hetzel, "Time dissemination via the LF transmitter DCF77 using a pseudo-random phase-shift keying of the carrier," PTB Braunschweig, 1988, [Online]. Available: https://www.ptb.de/cms/fileadmin/internet/fachabteilungen/abteilung_4/4.4_zeit_und_frequenz/pdf/5_1988_Hetzel_-_Proc_EFTF_88.pdf
- [5] -, "DCF77 webpage," 2024, Official page of the PTB [Online]. Available: <https://www.ptb.de/cms/en/ptb/fachabteilungen/abt4/fb-44/ag-442/dissemination-of-legal-time/dcf77.html>

IEEE conference templates contain guidance text for composing and formatting conference papers. Please ensure that all template text is removed from your conference paper prior to submission to the conference. Failure to remove the template text from your paper may result in your paper not being published.